Chemical Science International Journal
18(1): 1-9, 2017; Article no.CSIJ.31476
Previously known as American Chemical Science Journal
ISSN: 2249-0205

SCIENCEDOMAIN *international*
www.sciencedomain.org

Concentration Levels and the Associated Health Risks of Elements in Food Crops Grown in the Neighbourhood of Minjingu Phosphate Mine, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Author LLN designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author NKM supervised the analysis of the samples, reviewed the first draft and wrote the final manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CSJI/2017/31476
Editor(s):
(1) Dimitrios P. Nikolelis, Chemistry Department, Athens University, Greece.
Reviewers:
(1) Zhanibek Yessimbekov, Shakarim State University of Semey, Kazakhstan.
(2) Irfan Ersin Akinci, Kahramanmaras Sutcu Imam University, Turkey.
Complete Peer review History: http://www.sciencedomain.org/review-history/17790

Original Research Article

Received 7th January 2017
Accepted 28th January 2017
Published 10th February 2017

ABSTRACT

The concentration levels of heavy metals in food crops (maize and mung beans) grown in the neighbourhood of Minjingu Phosphate mine were analyzed using EDXRF. The metal concentrations in both food crops followed the following pattern Fe > Zn > Cu > Cd > Cr > Pb > As. Maize accumulated higher levels of all analyzed elements than mung beans. The concentration level of metals in maize and mung beans from Minjingu were higher than those from the control site. Except for Cd in both types of samples, the concentration levels of all other metals were below the FAO/WHO recommended limits. The risk assessment showed that consumption of mug beans from Minjingu is without any safety risk while there is a risk in consumption of maize due to the concentration of Cd. However, the number of samples was not sufficient enough to make a definite conclusion; therefore, there is need for further analysis to include more data.

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Keywords: Food crops; heavy metals; EDXRF; Minjingu phosphate mine; DIM and HRI.

1. INTRODUCTION

Heavy metals are potential environmental contaminants with a great capability of causing human health problems if present in excess in consumed food and water. A number of factors influencing the concentration of heavy metals within food crops have been reported [1]. These include the nature of the soil, agrochemicals used in farming and contaminants from other anthropogenic activities [2,3].

This study has analyzed food samples (maize and mung beans) collected from Minjingu village in Manyara, North of Tanzania. Due to the existence of large phosphate deposit in this village, there is also a phosphate mine and factory which process the phosphate rock into phosphate fertilizer. Studies have reported the presence of As, Cd, Cr, Pb, Ti, Mn, Fe, Cu, Zn, Rb, Sr, Y, Th and U in phosphate rocks in the world [4,5]. The concentration levels of the heavy metals in the rock will depend on its origin [4]. The Minjingu phosphate rock was also reported to contain elevated concentration of Ti, Mn, Fe Cu, Zn, Rb, Sr, Y, Th, and U higher than in many reported rocks [4,6]. There is a possibility that food crops grown in this area are contaminated with heavy metals from the deposit as well as from the activity of the mine/factory.

The exposure to heavy metals and related health risks to humans are usually expressed as percentage intake of provisional tolerable weekly intake (PWTI), a reference value established by WHO [7]. Most of the heavy metals are toxic at large concentration [8]. However, metals like Cd may be highly toxic even at very low concentrations [9]. International Agency for Research on Cancer (IARC) classified Cd and Pb as human carcinogen [10].

In this study we determined the concentrations of Cr, Fe, Cu, Zn, As, Cd and Pb in maize and mung beans grown in the neighbourhood of Minjingu Phosphate mine; and evaluated their concentration levels and their associated health risks with respect to international standard guidelines.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The Minjingu phosphate mine in Minjingu village is located to the east of the saline Lake Manyara along the rift valley escapement at Manyara region in the northern Tanzania at latitude 03° 42' 30.9" S and longitude 035° 54' 56.3" E (Fig. 1). The Minjingu village occupies approximately a land area of 24,000 hectares with a population of about 11,000 people [11]. Agriculture, pastoralism and phosphate mining are the land uses development in Minjingu village. Both food and commercial crops are grown at Minjingu village. Crops cultivated for subsistence living in the area includes maize, mung beans and cowpeas, while for income generation the crops include water melon, cotton and sesame.

2.2 Food Crops Sampling

In this study, Maize and mung beans were identified as the main staple foods hence were collected for analysis. A total of 20 samples of maize (mass 1000 g each) and 13 samples of mung beans (mass of 1000 g each) were collected in farms within an area covered with a radius of 6.82 km from the Minjingu phosphate mine to the North, West and Southern of the village (Fig. 1). For comparison, two control samples (one for maize and the other for mung beans) were collected from Magugu Village in Manyara.

2.3 Sample Preparation

The food crops were washed as would be done during normal food preparation to remove any surface deposits. Then the samples were dried into oven at 48°C for 4 days. And finally were grinded and sieved through a 2 mm-sieve into powder, packed and stored into the descator for a week to attain a constant weight before analysis.

A dry weight of 12 grams of maize sample with 2.7 grams of cellulose binder were put into a bowl together with four spherical balls, each with 3 mm radius and fixed to a pulveriser machine which was further ground and homogenized. The machine was set at a speed of 150 revolutions per minute (rpm) for 15 minutes. The analyte was placed into a polished, lapped thrust piece with a smooth surface and fixed into hydraulic press machine. A pellet in tablet form was obtained by applying an average pressure of 12.5 tons. The same processes were applied to 12 grams of mung beans samples. Each pellet was labeled and subsequently placed in a transparent plastic sample holder ready for measurements in Energy Dispersive X-Ray Fluorescence (EXRDF) Machine.

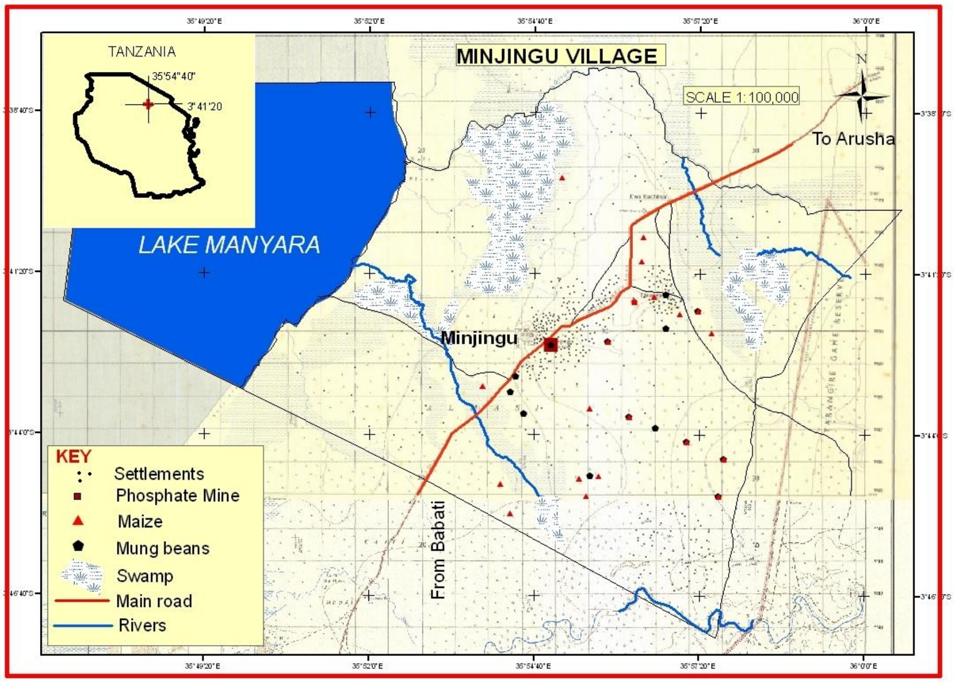

Fig. 1. The map of Minjingu Village showing the food sampling sites

2.4 Sample Analysis

The elemental analyses of samples were conducted using a bench top energy dispersive X-ray spectrometer of Tanzania Atomic Energy Commission (TAEC) in Arusha. The machine which is operated by automated turbo-quant X-lab Pro^{TM} software uses a 0.003 beryllium window X-ray tube with copper body anode and ceramic envelope with palladium target. The X-ray tube was operated at a power of 50W and 50kV voltage. The florescent X-rays were collected by a Si (Li) detector having a resolution (FWHM) at MnK_α ≤160 eV.

The excitation of elements in the sample was carried out using three secondary targets. Light elements from Na-V were excited using high oriented pure graphite (HOPG) target (intense monochromatic polarized X-Rays). The Elements from Cr-Zr and Pr-U were excited using Mo secondary target (intense monochromatic non-polarized X-Rays). The high energy elements Y-Ce were excited using Barkla target (Al2O3) (intense polychromatic polarized X-Rays) [12]. The spectrum in Fig. 2 is an example of the typical spectra obtained in this study for 20 min and it gave a good continuity statistics and resolution of the peaks.

Concentrations of elements in the samples were calculated by the inbuilt software called X-lab Pro^{TM} with Turboquant (Tq 9232) algorithm for matrix effect correction [13]. The software corrects for the matrix effects (*Mi*) and the interference effects (*Ki*) basing on fundamental parameter methodology. The software corrects also for the background effect on a spectral line intensity (*Ii*), given as counts per second (cps). After all the corrections, the software converts the intensity into concentration of the element using Eq. (1) [14].

$$C_i = K_I \times I_I \times M_a \tag{1}$$

Where *Ci* is the concentration of a given element *i*; Ma is the correction factor for matrix effects. *Ki* is the constant of proportionality; *Ii* is the intensity of the fluorescent radiation from the element *i.*

Quality control was carried out using two IAEA reference materials for Trace and Minor Elements. The first one was Cabbage (IAEA 359) [15] and the second was Soil (IAEA-Soil 7) [16] both were analyzed simultaneously with the food samples. As Table 1 shows, the experimental values were all in good agreement with the recommended values and there were also within 95% confidence interval given in the reference sheets except for Cd only.

Table 1. Experimental and recommended values (mg/kg) of reference material trace and minor elements (Fe, Cu, Zn and Cd) in cabbage (IAEA 359) [15] and minor elements (Cr, As and Pb) in IAEA-soil 7 [16]

Elements	Experimental values	Recommended values	95% confidence Interval from the data sheet [15,16]
Cr	76.36	60.00	49 – 77
Fe	150.00	148.00	144.1 - 151.9
Cu	5.48	5.67	5.49 - 5.85
Zn	36.77	38.60	37.9 – 39.3
As	12.71	13.40	12.5 – 14.2
Cd	0.09	0.12	0.115 – 0.125
Pb	55.44	60.00	55 – 71

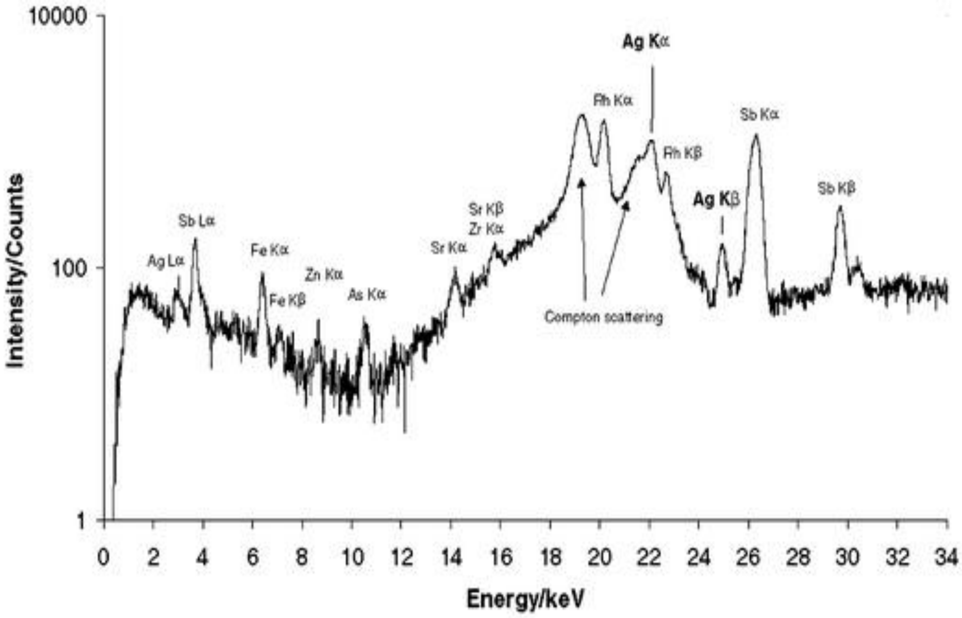

Fig. 2. A typical example of the spectrum showing the Kα and Kβ characteristic lines in EDXRF analysis

2.5 Health Risk Assessment for Local Inhabitant

2.5.1 Daily intake of metals (DIM) through food chain

In this study, a small survey was conducted to collect a food consumption pattern specifically for Minjingu population in order to estimate the food consumption rates for the selected food crops. The procedures for food consumption rate estimation were described [17]. The food consumption rates were found to be 151.2 kg capita^{-1} year^{-1} and 11.9 kg capita^{-1} year^{-1} for maize and mung beans, respectively. Therefore, for a day we have 0.413 kg/person per day and 0.033 kg/person per day for maize and mung beans, respectively. The DIM was estimated using the following equation [18]

$$DIM = \frac{C_i \times K \times I}{W} \quad (2)$$

Where:-

- C_i: Heavy metal concentration of element *i* (mg/kg)
- K: Conversion factor (0.085) [19]
- W: The average adult body weights (60 kg) [7]
- I: Daily food intake (0.413 and 0.033 kg/ person per day for maize and mung beans, respectively).

2.5.2 Health risk index

The health risk index (HRI) for the locals in Minjingu village through the consumption of contaminated maize and mung beans was assessed based on the food chain and the reference oral dose (RfD) for each metal. In general, the RfD is an estimate of a daily exposure to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime [20]. The following equation given by USEPA [18] was used to calculate HRI, note that for HRI < 1, the exposed population is assumed to be safe [18].

$$HRI = \frac{DIM}{RfD} \tag{3}$$

3. RESULTS AND DISCUSSION

3.1 Heavy Metals in Maize (*Zea mays*) and Mung Beans (*Vigna radiate)*

Heavy metals in foods have the maximum allowable limits specified by different bodies or organisations. This study adopted the standards issued by FAO/WHO. Therefore, a comparison and interpretation of the results is based on the control values, concentration levels of similar samples from different countries and standards set by FAO/WHO.

The concentrations of the four heavy metals (Cr, As, Cd and Pb) as well as the three trace elements (Fe, Cu and Zn) in maize and mung beans analyzed on dry weight basis are presented in Table 2. The results shows that, all the selected metals were detected in maize and mung beans samples from Minjingu except Pb in maize and As in both maize and mung beans. The concentrations of these metals in maize and mung beans from Minjingu village were higher than those obtained in samples from the control site (Table 2). For instance, the mean concentration of Cd in maize from Minjingu is 1.7 times higher than its value in control sample.

The concentration levels of As in all samples were found to be below detection limit of the instruments used in this study. The mean value of Pb in mung beans was found to be 0.02 ±0.00 mg/kg this value is below the allowable limit of 0.3 mg/kg set by FAO/WHO [21]. Cadmium (Cd) in maize and mung beans were found to be 2.63 ± 0.55 mg/kg and 1.15 ± 0.74 mg/kg, respectively. These values are above the allowable limit of 0.2 mg/kg [21]. On the other hand, the mean concentration of Cr was found to be 0.73 ± 0.02 mg/kg and 0.69 ± 0.02 mg/kg in maize and mung bean, respectively. However these values are below the allowable limit for Cr in food [21].

The mean concentration levels for As, Cr and Cd were compared with their concentrations reported in maize and mung beans from elsewhere. The mean concentration level of Cr in mung beans from Minjingu is found to be much lower than that reported in mung beans from India [22]. The levels of As detected in maize and mung beans from China were higher compared to that of Minjingu which was bellow the detection limits of the experimental technique used (0.4 mg/kg). Concentration of Cd in Minjingu samples was found to be higher than the reported levels in maize and mung beans in Nigeria, Egypt, Philippines, China and India [8,22,23–27].

On the other hand the concentrations of Fe, Cu and Zn were higher than the concentration levels of Cr, As, Cd and Pb in each sample. In fact, Fe, Cu and Zn are essential elements for human health and have numerous functions in the human body. For instance, Fe is an essential element for human beings and animals and is an essential component of hemoglobin [8,17]. Cu serves as an antioxidant and helps the body to remove free radicals and prevent cell structure damage and Zn function as a cofactor for many enzymes of the body [17]. The concentrations of trace elements (Fe, Cu and Zn) in maize ranged from 61.09 – 142.64 mg/kg for Fe, 3.17 – 5.33 mg/kg for Cu and 37.40 – 73.68 mg/kg for Zn. For mung beans, the concentration of essential elements ranged from 73.70 – 134.76 mg/kg for Fe, 3.28 – 8.33 mg/kg for Cu and 18.39 – 31.83 mg/kg for Zn.

The concentrations of Fe, Cu and Zn in the present study were compared with their concentrations is samples from other countries (Table 4). The mean concentration of Fe found in this study was higher than the concentration reported in maize from Nigeria (Table 3). However, the Concentration level of Fe in mung beans from India was higher than that from Minjingu by a factor of 2 [22]. The mean concentration levels of Cu in samples of maize in this study was found to be similar to its concentration found in maize from Ogun state in Nigeria and in mung beans from India (Table 4). However, Cu was found to be lower in

Table 2. Mean concentration of heavy metals (Mean ± SEM) in mg/kg (ppm) recorded from Maize and mung beans sampled from Minjingu village and that from the control site and the safe limits of heavy metals according to FAO/WHO [21]

Metal	Minjingu samples		Control samples		FAO/WHO (Safe limits) [21]
	Maize	Mung beans	Maize	Mung beans	
Cr	0.73 ± 0.02 (0.60 – 0.90)	0.69 ± 0.02 (0.56 – 0.87)	0.26 ± 0.02	0.23 ± 0.02	2.3
Fe	110.64 ± 5.72 (61.09 – 142.64)	102.59 ± 5.25 (73.70 – 134.76)	36.26 ± 0.49	75.70 ± 1.44	425.5
Cu	4.10 ± 0.13 (3.17 – 5.33)	6.08 ± 0.39 (3.28 – 8.33)	1.00 ± 0.05	2.42 ± 0.13	73.3
Zn	56.74 ± 2.11 (37.40 – 73.68)	24.81 ± 1.19 (18.39 – 31.83)	17.24 ± 0.34	9.76 ± 0.44	99.4
As	BDL (--)	BDL (--)	BDL	BDL	--
Cd	2.63 ± 0.55 (0 – 8.16)	1.15 ± 0.74 (0 – 7.60)	1.55 ± 0.12	0.52 ± 0.12	0.2
Pb	BDL (--)	0.02 ± 0.00 (0 – 0.12)	BDL	BDL	0.3

**Values in bracket present the range*

Table 3. DIM and HRI for individual heavy metals caused by the consumption of Maize and Mung beans collected from Minjingu village

Metal	DIM in maize (mg/kg per day)	DIM in Mung beans (mg/kg per day)	RfD [20,21] (mg/kg per day)	HIR (Maize)	HIR (Mung beans)
Cr	4.27E-04	3.23E-05	1.5E+00	2.83E-04	2.15E-05
Fe	6.47E-02	4.80E-03	7.0E-01	9.25E-02	6.84E-03
Cu	2.40E-03	2.84E-04	4.0E-02	6.00E-02	7.09E-03
Zn	3.32E-02	1.16E-03	3.0E-01	1.11E-01	3.85E-03
As	0	0	3.0E-03	0.00E+00	0.00E+00
Cd	1.54E-03	5.38E-05	1.0E-03	1.54E+00	5.32E-02
Pb	0	9.35E-07	3.5E-03	0.00E+00	2.66E-04

Note: The DIM < RfD in all the metals except for Cd in maize

mung bean in Nigeria and higher in Egypt and China [8,23–27]. Zn in mug beans from Minjingu was found to be lower than its value reported in Nigeria and China [25,27].

3.2 Health Risk Assessment for Local Inhabitant

To assess the health risk of inhabitants of these food crops in Minjingu village, the daily intakes rates of metals (DIM) and health risk index were estimated. The daily intake of heavy metals was estimated according to the average maize and mung beans consumption using equation 2. The results of the DIM for adults are given in Table 4. As the table shows, the values of daily intake of metals (DIM) were higher for maize when compared to that of mung beans. The DIM for Minjingu inhabitants via consumption of contaminated food crops may cause severe health risk by ingestion of Cd in maize; the daily intake of Cd is 0.00154 mg/kg body weight. This value is approximately twice as much as the tolerable daily intake (TDI) of Cd [28]. However, the estimated dietary intakes (DIM) for other remained metals (Cr, Fe, Cu, Zn, As and Pb) were far below the tolerable limits.

In the present work the mean concentration of each metal (in terms of DIM) was used to calculate its health risk index (HRI) using equation 3. The HRI has been recognised as a very useful index to evaluate the health risks associated with the consumption of heavy metals contaminated food crops [18]. The data indicated that except for the concentrations of Cd in maize samples, the HRI values for all the other metals analysed in this work were < 1 (Table 3).

Table 4. Concentration of metals in mg/kg (ppm) in maize and beans samples from Minjingu and similar samples from other countries

Metal	Present study (Minjingu)	Nigeria [24[a], 25[b], 26[c], 29[d]]		Egypt [8]	Philippines [27]	China [23] (Hunan)	India [22] (South Bolanda)
Cr	0.73 ± 0.02	--	---	--	--	--	--
	(0.69 ± 0.02)	--	(BDL)[c]	--	--	--	(8.61 ± 0.86)
Fe	110.64 ± 5.72	28.5- 59.5[d]	0.2-0.34[b]	--	--	--	--
	(102.59 ± 5.25)	--	(7.95±0.59)[c]	--	--	--	(272.8 ± 4.82)
Cu	4.10 ± 0.13	2 - 10.7[d]	0.24-0.48[b]	0.46 ± 0.08	0.145-0.943	2.43-10.10	--
	(6.08 ± 0.39)	(0.02 ± 0.19)[a]	(3.65±0.42)[c]	(8.01 ± 0.59)	--	(12.92-22.98)	(5.53 ± 3.70)
Zn	56.74 ± 2.11	--	0.03-0.05[b]	15.45 ± 2.94	1.737-3.279	41.73-88.79	---
	(24.81 ± 1.19)	(1.08 ± 0.23)[a]	(30.0±0.04)[c]	(14.53 ± 4.05)	--	(74.00-97.08)	(3.42 ± 0.24)
As	BDL	--	0.02-0.28[b]	---	--	0.12-1.48	--
	(--)	--	--	---	--	(1.33-7.87)	--
Cd	2.63 ± 0.55	--	0.11-0.14[b]	0.14 ± 0.03	0.021-0.081	0.03-0.47	--
	(1.15 ± 0.74)	(0.02 ± 0.17)[a]	--	(0.06 ± 0.05)	--	(0.34-0.67)	--
Pb	BDL	62.5-150[a]	0.03-0.23[b]	0.12±0.06	0.112-0.676	0.18-1.91	--
	(0.02 ± 0.00)	(BDL)[a]	--	(0.28±0.26)	--	(5.82-13.33)	--

Values in brackets present the conc. for Mung beans

Therefore, the health risk of heavy metal exposure through the food chain is minor. The health risk caused by the consumption of maize from Minjingu due to Cd alarming hence; further analysis which will include more samples is needed to have a definite statistical conclusion. Cd is toxic and carcinogenic even at very low concentration [9,10]. Hence its presentce in the food chain should be followed further.

The calculated DIM and HRI in this work might be variable. This is because; the calculation of food consumption rates assumed no importation of maize and mung beans from outside the Minjingu village. However, in some cases depending on the climatic conditions of a particular year, the harvest might become insufficient to serve for the whole year, and the villagers had to import food from other areas. Hence, the DIM and HRI might not be the same as those presented in Table 3.

4. CONCLUSION

The concentration levels of heavy metals in food crops (maize and mung beans) grown in the neighbourhood of Minjingu Phosphate mine were analyzed using EDXRF. The maize and mung beans in Minjingu are cultivated in small scale, they are just for subsistence and hence mostly consumed by the rural population of the Minjingu village. The results have shown that the concentration level of metals in maize and mung beans from Minjingu were higher than those from the control site. Moreover, maize has shown to accumulate higher levels of all analyzed elements than mung beans. The results presented also that there is no risk associated with consumption of mung beans grown in Minjingu village as far as the FAO/WHO recommended limits are concerned. However, for the case of maize, the HRI for Cd is higher than 1. Hence, the study recommends that, people living in Minjingu village should not eat large quantities of maize, so as to avoid excessive accumulation of Cadmium (Cd) in their bodies; Cd is highly toxic even at very low concentrations. Dietary intake of food results in long-term low level body accumulation of heavy metals and the detrimental impact become apparent only after several years of exposure. Therefore, further analysis which will include more samples is needed to have a definite statistical conclusion on the safety consumption of maize grown in Minjingu.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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DOI: 10.11648/j.ijsts.20130102.12

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17790